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Role of *Ricinus communis* Plants: As Highly Adsorbent Surface for Removal of Dyes from Aqueous Solutions and Its Role of Biological Activity

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Abstract: In this study, leaves from perennial plants, *Ricinus communis, RC* was used. It's a natural form without any chemical treatments. The obtained powders are characterised by utilising several methods like (UV–Vis) Spectroscopy, EFSEM, TEM, FTIR, and XRD. The adsorption system is one of the most significant ways to eliminate contaminants such as brilliant blue and BB dye from aqueous solutions, depending on several factors that can be affected by the adsorption process, like contact time, where the best equilibrium time was after 1 hr. The effect of the adsorbent dosage from 0.025 g/100 mL to 0.12 g/100 mL that was found when weight increased removal percentage increased from 63.34% to 96.54% respectively. On the contrary, the adsorption efficiency decreased from 95.12 mg/g to 40.56 mg/g, the effect concentration of BB dye from 10 mg/L to 100 mg/L was found with an increased concentration of BB dye, the adsorption capacity increased from 10.23 mg/g to 62.56 mg/g, respectively, the effect of pH of solution (3.00-10.00) and the best adsorption efficiency found at pH = 6.00. A comparison was also made between natural *Ricinus communis*, *RC* and natural fruits *Ricinus communis*, *FRC*, activated untreated-acid *Ricinus communis* Pericarp, *ARC* and acidic-treated *Ricinus communis* pericarp, *ACRC*. Also, adsorption isotherms were studied for both Langmuir and Freundlich models, It was found that results followed Freundlich isotherm by depending on the value of (r^2 = 0.9559) and also on heterogeneous surfaces. The thermodynamic parameters studies find the sorption BB dye was negative by the value of Gibbs free energy which means the process is (spontaneous), While enthalpy changes are positive (endothermic). The values of the positive of ΔS are not very large and agree with the decrease in the degree of freedom. The performance and reuse of *RC* by using 0.01 N HCl in the adsorption process of dyes were investigated up to 6 cycle under best conditions. Results showed that the surface of *RC* has biological activity against the Gram-negative bacteria compared to the Gram-positive bacteria with an inhibition area (20 mm).

Key words: Adsorption, removal, brilliant blue, dye, thermodynamic, isotherm model.

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Introduction

The textile dyeing industry has been around for more than 4,000 years. The major shift in textile dyes occurred after 1856 during the knowledge of how to manufacture quinine, a drug that treated malaria and the plague. Pigments are insoluble and remain in the form of particles, while dyes are synthetic organic compounds that dissolve in water or oil. Various organic dyes are used in textiles to colour various products. Their chemical compositions are numerous and include dyes with very different chemical and physical properties, such as azo and nitro dyes, phthalocyanine dyes, and diarylmethane dyes (Yongde et al., 2020). Complex unsaturated chemical compounds called pigments absorb light and give visible colour. Pigments are usually coloured, colourless or fluorescent colouring agents that are usually finely divided solids and powders that are insoluble in a compact medium. Sample of dyes have been found in environmental components such as water (river, pond, drinking water, wastewater), suspended particles, sediments, soil, and wild fish (Sevda et al., 2021, Shweta et al., 2022, Sharma et al., 2021). Water could be polluted mainly with dye, drugs, heavy metals, radioactive materials, sediments, and organic and inorganic materials (Sharma et al., 2022). Among the most important of these toxic and dangerous pollutants are textile dyes, which is a major source of water pollution as and cause great concern due to their bioaccumulation, toxicity, high stability and inability to biodegrade (Aljeboree et al., 2023).

Brilliant blue, dye odourless blue-yellow to blue powder, is one of the generally identified basic dye. Brilliant blue colour causes severe allergic reactions in the digestive and respiratory system (Khalil and Abdullah, 2024).

Ricinus communis, *RC* is a perennial shrubby plant, ranging in height (r) from a meter, the stem is woody, and hollow when mature. The leaves are usually large in size, petiole, simple, lobed, dark green. The female and male flowers are on the same plant and are arranged in clusters. The fruits are split into three fruits, each fruit containing one seed (Al Rmalli et al., 2008). The *Ricinus communis* L. plant belongs to the Euphorbiaceae family and grows in most hot areas. The seeds of this plant usually contain toxic compounds. This plant is classified as a dry plant that loves sunlight and its leaves are divided into several leaflets. Its leaves are also distinguished by their large size, with the colour of the leaves varying depending on the growth of the plant. It is used in many medical fields (Magriotis et al., 2014; Shaban et al., 2008).

In this study, the leaves of the *RC* were used as an effective adsorbent surface of environmentally friendly, cheap, and available for the elimination of BB from water. A comparison was also made between *RC, FRC, ARC,* and *ACRC*. Several factors were studied such as adsorbent dosage, dye concentration, effect of pH, and adsorption isotherms. Also, the surface *RC* has biological activity.

Experimental

Characterisation of the Prepared *Ricinus communis*, *RC*

FT-IR spectra were recorded by the FT-IR instrument (Shimadzu. 8400S) in the 4000-400 cm^{-1}. Thermodynamic TGA is performed to determine the thermal stability of the prepared material. The sample is heated from 5 to 600 °C and at a heating speed of 5 °C/min. FE-SEM is a technique used to characterize sample morphology such as particle size, grain size, particle distribution, surface structure, and crystalline size. The technique (TEM) is considered one of the most important microscopy techniques that usually uses a beam of electrons transmitted through a very thin sample, where it can transform the electrons into light and form an image. X-ray diffraction technology is considered one of the most important techniques for determining the crystalline structure and studying the features and properties of the prepared material, and also to determine whether it is a crystalline or non-crystalline material.

Preparation of *Ricinus communis*, *RC*

The castor plant called *RC* is a perennial shrub, obtained from farms in Iraqi cities. The surface was prepared by washing *RC* and *FRC* with DW to get rid of suspended dust, then these surfaces were dried under natural sun light for 6 hrs. then ground to obtain soft powder. Acidified activated carbon was prepared by adding 0.1 N hydrochloric acid with stirring for about 2 hrs., the product was washed with DW until the solution pH was 7.0 ± 0.2. Then it was dried in an oven at (75 ± 5) ºC for 12 h. Lastly, the product was burned at a temperature of 300 ºC to obtain activated carbon *ACRC*. It was stored in a bottle and airtight to use in the next experiments. The same previous experiments were used to prepare *ARC* without the acid treatment, as shown in Figure 1

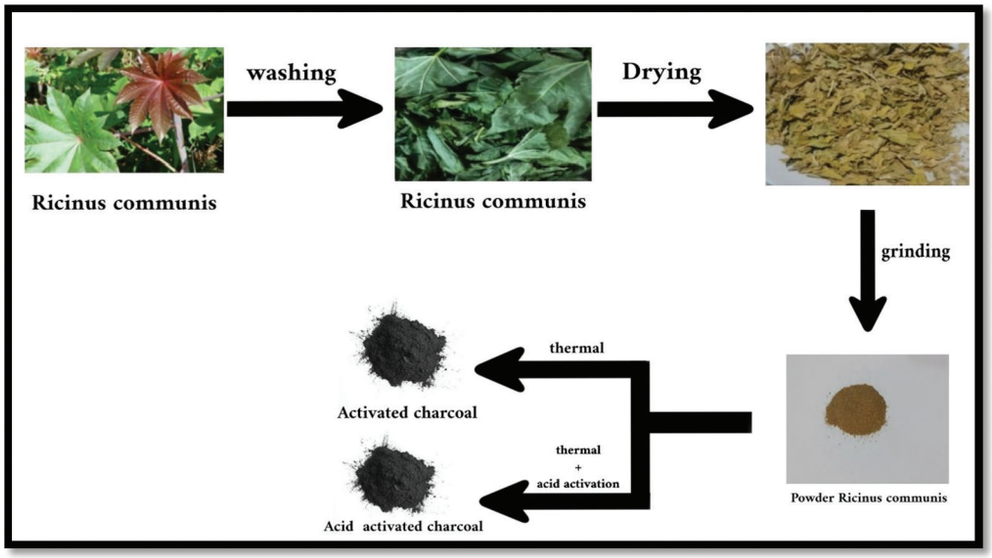

Figure 1: Preparation of *RC* surface.

Batch Mode Adsorption Studies

A standard solution of BB dye 1000 mg/L was prepared by 1.0 g of dye in distilled water. Several concentrations of BB dye (10-100) mg/L were prepared. Batch adsorption studies were carried out with 0.08 g of *RC* in 100 mL of solution dye of desired concentration at a pH = 6.0 solution in conical flasks 100 mL, that agitated at 130 rpm at (25 °C) in a shaker water bath. Following agitation, the *RC* and dye were separated via centrifugation, and dye concentration in the supernatant solution was measured by using a spectrophotometer at 620 nm. The effect of *RC* amount on removal percentage was studied from (0.025, 0.120) g /100 mL whereas the different concentrations of dye at 10 mg / L and 100 mg / L. Effect of pH (2-10) on dye removal was studied using 0.08 g *RC* of solution 100 [mg /L]. The *E* [%] and Q_e [mg/g] of dye were calculated via equations:

$$E\ (\%) = \frac{Co - Ce}{Co}\ 100 \qquad (1)$$

$$Qe = \frac{(Co - Ce)V}{W} \qquad (2)$$

where: C_o the primary concentration of BB dye [mg/L], and *Ce* is the equilibrium concentration of BB dye [mg/L] at time *t* [min], *V* is the volume of BB solution [L], and *W* is the weight of RC [g].

Results and Discussion

Adsorbent Characterisation

FT-IR spectra of surface *RC* before and after dye-adsorbed on the surface are shown in Figure 2. Results

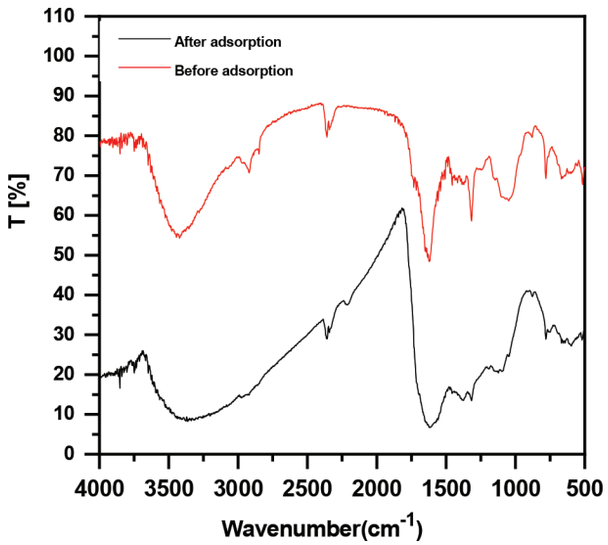

Figure 2: FT-IR spectra of surface RC before and after adsorption of BB dye.

show that some peaks were shifted in the spectrum of surface *RC* before adsorption. There is a strong peak at 3429 cm^{-1} representing the −OH stretching. The broadband around 3435 cm^{-1} and 2927 cm^{-1} is characteristic of the stretching of the –OH groups and the C–H stretching of the CH_2 groups, in the same order. Starting by the *RC* at 3400 cm^{-1}, 1600 cm^{-1}, and 1409 cm^{-1} assigned in the same order to the stretching vibration of –OH from the hydroxyl group to C=O, and to symmetric COO− vibrations stretching (Herrera-Gonz´alez et al., 2019).

Figure 3 shows an image of the prepared surface adsorption method before and after using the FESEM technique for *RC*. The surface before the adsorption

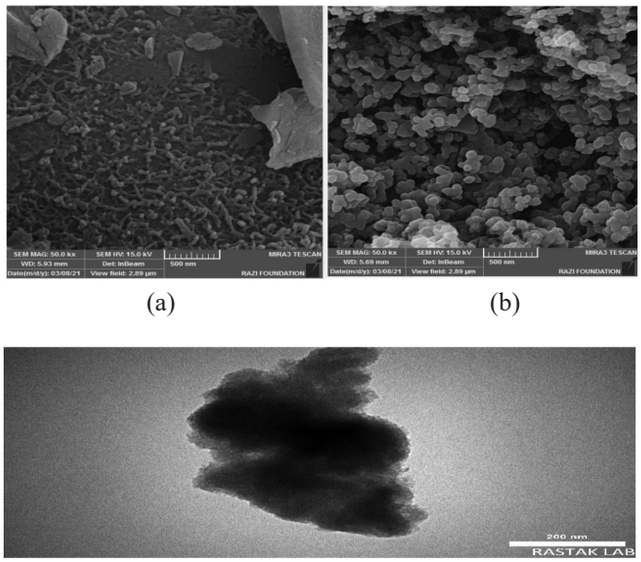

Figure 3: FESEM of *RC*: a) before adsorption, b) after adsorption and c) TEM image of *RC*.

method has a wide-pore structure. It was also noted that the surface contains many gaps and capillary channels. It was noted that the surface after the adsorption method contains bulges and blockage of many because of loading dye onto the surface. Figure 3c illustrates the TEM images of the *RC*. An internal structural image represents the surface, where the morphology of the surface was in the form of spherical clusters forming a dark cloud (Yanti et al., 2023).

X-ray diffraction patterns of *RC* shown in Figure 4, which indicates that *RC* is amorphous, therefore *RC* look to be non-crystalline materials that are clear from the peaks present in the broadband in the case of a surface (Sharma et al., 2022).

Effect Weight of RS

Figure 5 displays the influence of the amount *of RC* on dye adsorption. The percentage of removal of dye increases with increasing amount of *RC* and reaches the best removal (94.97%) at a particular *RC* amount. It can be seen from Figure 5 that the best removal percentage of dye necessary from an aqueous solution is 0.08 g for 100 mg/L. The percentage of dye increases with the amount of *RC* increase is due to a rise in the surface area resulting in the number of particles with increased active surface sites number for the adsorption and saturation as a result of no availability of dye molecules to adsorption (Gebeyehu et al., 2024; Hamadneh et al., 2022).

Effect of Concentration BB Dye

Effect concentration of BB dye onto removal BB was

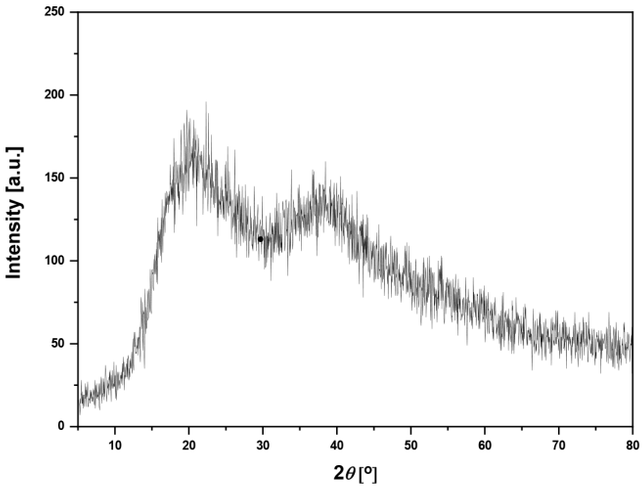

Figure 4: X-ray diffraction patterns *RC*.

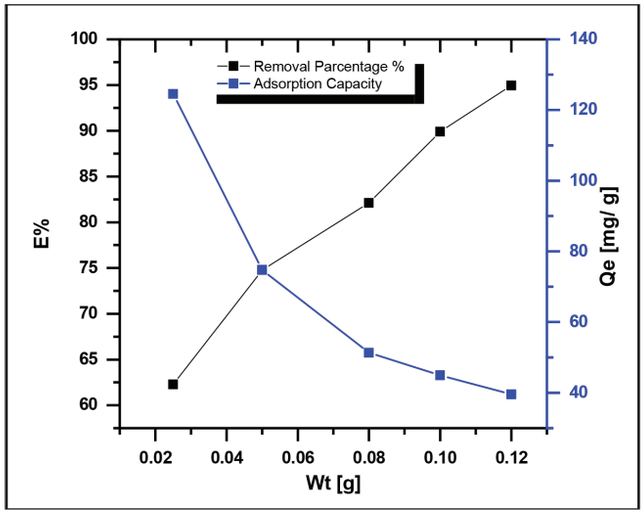

Figure 5: Effect of weight of RC to removal BB dye.

detected at 10 mg/L-100 mg/L. A 100 mL solution of BB dye was poured in a 100 mL conical flask at (25 ^{o}C) and was agitated at 130 rpm via utilisation 0.08 g of *RC* as appears in Figure 6. It is possible to verify that the amount adsorbed of dye increased through the increase of the initial *BB* dye concentration. When the initial dye concentration rises from 10 mg/L to 100 mg/L, the adsorption efficiency rises from 10.12 mg/g to 65.25 mg/g due to the increase of driving forces. Besides a decrease in removal percentage from 98.67 % to 64.87 % with increased dye concentration (VenturaR et al., 2022).

Influence of Solution pH

The influence pH solution ranges from 2.0 to 10.0 on BB dye adsorption capacity via the adsorption process. Adsorption of dye increases with pH increase. Lower adsorption of dye at acidic pH was possibly due to the

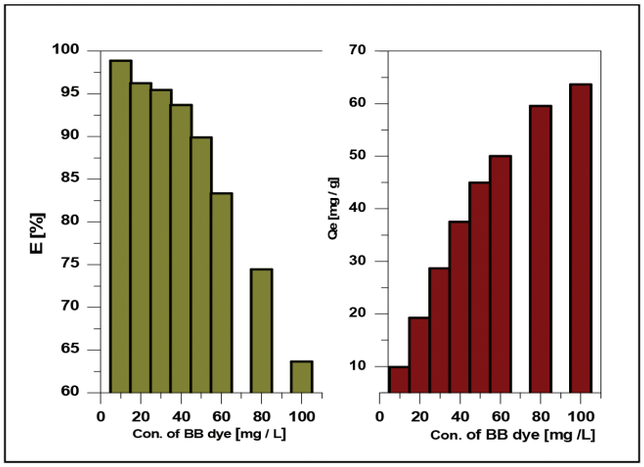

Figure 6: Effect of dye concentration adsorption using *RC* (pH = 6.0, T 25, and adsorbent dosage 0.08 g/L).

presence of excess H^+ ions competing with the dye cation for the adsorption sites. The maximum uptake of adsorbate was the best at a pH of 6.0, with an adsorption efficiency of 46.69 mg/g of *RC*. Thus pH 6 was selected as the optimum for adsorption as shown in Figure 7 (Radia et al., 2022)

Comparative Adsorption at Several Surfaces for Removal of *BB* Dye

A comparative study between surfaces as adsorbents like (*RC, FRC, ARC* and *ACRC*) was carried out. A 100 ml solution of concentration 100 [mg/L] BB dye was used in this study, then poured in an elementary of 0.08 g from *RC*, and lay at a control temperature for 60 min., after that the supernatant was separated through centrifuge and the residual concentration of dye was measured by utilising UV-Vis spectrophotometer at the λ_{max} nm. The preferable results of the elimination of BB dye (in increasing order): *RC* > *FRC* > *ARC* > *ACRC* are displayed in Table 1.

Table 1: Comparative adsorption at several surfaces to removal BB dye

Adsorbent	*Removal percentage [%]*
ACRC	40.56
ARC	61.23
FRC	90.45
RC	95.45

Adsorption Isotherm Model

Langmuir model is the best known and utmost utilised of all models describing adsorption and it has been

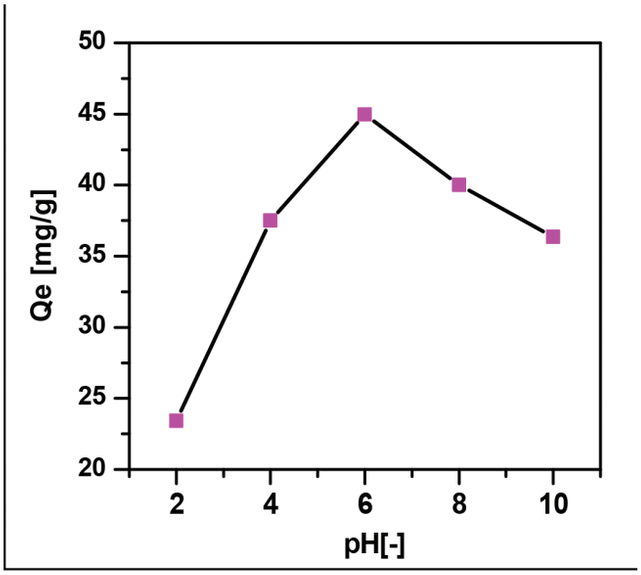

Figure 7: Influence of solution pH in adsorption uptake of BB onto *RC*.

useful successfully in a lot of adsorption ways. Isotherm was calculated by equations:

$$Q_e = \frac{Q_m K_L C_e}{1 + K_L C_e} \quad (3)$$

The isotherm Freundlich model is defined out of the non-linear form of equation:

$$Q_e = k_f Ce^{\frac{1}{n}} \quad (4)$$

where Q_e is a quantity adsorbed per unit mass of adsorbent at equilibrium [mg/g], C_e is the equilibrium concentration of adsorbate in solution after adsorption [mg/L], Kf: Empirical capacity factor or Freundlich constant [L/mg] - this represents the amount of dye adsorbed for a unit equilibrium concentration. 1/n: Freundlich exponent - If the value of n is equal to unity, the adsorption is linear. If the value is below unity, then the adsorption process is chemical. If the value is above unity, then the adsorption is a physical process as shown in Table 2. Figure 8 shows a plot of Q_e vs. C_e, where the values of Kf and 1/n are determined by the intercept and slope in the same order (El-Aryan, 2024, Sharma et al., 2022). The Q_{max} of the *RC* was compared with those of other t adsorbents reported in the literature, as shown in Table 3. As expected, the nanocomposite exhibits a higher Q_{max} value than the majority of conventional hydrogel-based adsorbents (Ahmad, 2009; Aljeboree et al., 2015; Borah et al., 2010; Saeed et al., 2010).

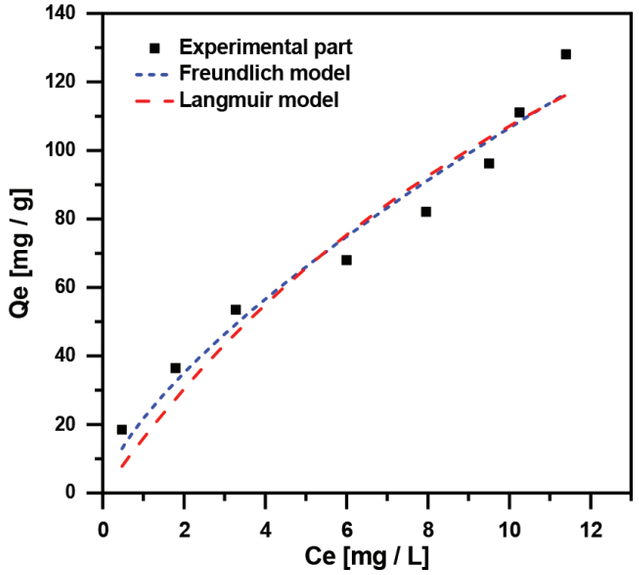

Figure 8: Adsorption isotherm non-linear fitted of adsorption *BB* onto *RC*, adsorption dosage = 0.08 g , conc. = 100 mg/L, T = 25 °C.

Table 2: Factors of Langmuir and Freundlich isotherms of BB adsorbed onto *RC*

Isotherm	*Factors*	*Ricinus communis*
Freundlich	K_F	21.724 ± 4.021
	1/n	0.690 ± 0.0847
	R^2	0.9559
Langmuir	q_m (mg/g)	129.187 ± 28.965
	K_L(L/mg)	0.0582 ± 0.0385
	R^2	0.9123

Thermodynamic Parameters

Thermodynamic factors were carried out to determine the Change enthalpy (ΔH), free change energy (ΔG), and change entropy (ΔS) in the different temperature solution series (288, 303) K and the thermodynamic factors are determined by the following equations (Mohammed et al., 2018):

$$\Delta G = -RT \ln K_{eq} \quad (5)$$

where ΔG: Gibbs free energy [$J{\cdot}K^{1-} \cdot mole^{-1}$], R is the gas constant [8.314 $J{\cdot}K^{1-} \cdot mole^{-1}$], T is the absolute temperature [K]

According to thermodynamic law, the calculation of the Van't Hoff equation as follows:

$$\Delta G = \Delta H - T\Delta S \quad (6)$$

Equation (7) can be further transformed as follows:

$$\ln K_{eq} = - \Delta H/RT + \Delta S/R \quad (7)$$

The thermodynamic parameters studies find of the sorption *BB* dye appear in Figure 9 and Table 4. The value of Gibb's free energy was negative which means the process is spontaneous (Noubigh, 2024). While the results show the change in enthalpyis positive, this is attributed to the process as endothermic. The values of positive ΔS are not very large and agree with a decrease in the degree of freedom (Samiyammal et al., 2022).

Biological Activity

In the study, the two kinds of bacteria were Gram-negative bacteria GNB (*E coli*), and Gram-positive bacteria GPB (*Staphylococcus aureus*) using one isolate

Table 3: A comparison of the maximum adsorption efficiency of RC and other report adsorbents

Adsorbent	*Adsorption condition*			*Q max (mg/g)*	*Ref.*
	Conc. mg/L	*T °C*	*pH*		
Ricinus communis (Nakorchevsky and Yates).	50	25	7.4	37.23	(Shaban et al., 2008)
Ricinus communis (Nakorchevsky and Yates)	50	30	6	27.22	(Santhi et al., 1016)
Castor bean (*Ricinus communis*)	20	20	٤	55.7	(Magriotis et al., 2014)
Ricinus communis (Nakorchevsky and Yates).	50	25	6	87.22	(Magriotis et al., 2014)
(SA-g-P(ITA-co-NaSS)/CPL)	700	30	6	1433	(Aljeboree et al., 2024a)
(SA-g-P(ITA-co-VBS)/RC)	800	30	7	235.59	(Aljeboree et al., 2024b)
Ricinus communis (Nakorchevsky and Yates).	100	25	7	120.77	In this study

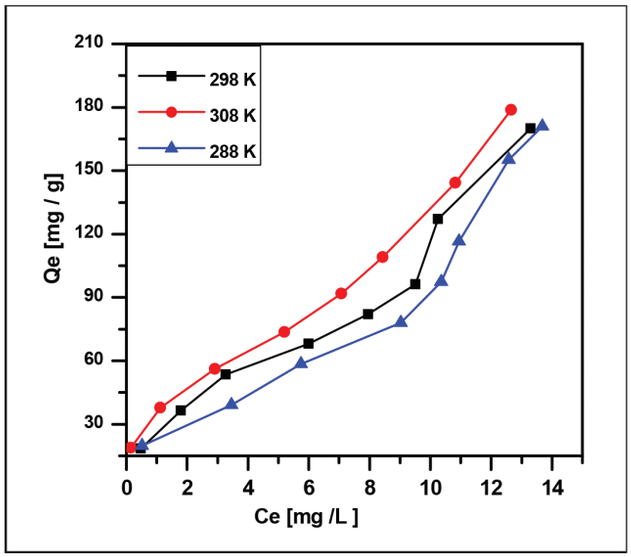

Figure 9: Isotherm adsorption models of BB onto RC at several temperatures

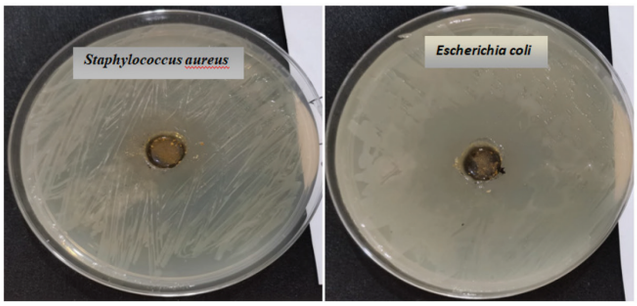

Figure 10: Antibacterial activities of the RC using disc diffusion method.

depending on the method of disc diffusion, where two concentrations of 0.1 g, from the *RC*, the results showed that the surface *RC* have anti-bacterial activity against (GNB) compared to (GPB)with an inhibition 20 mm, as shown in the Figure10.

Table 4: Thermodynamic factors for BB adsorption on to *RC*

Thermodynamic factor			
ΔG [kJ/mol]	*ΔH [kJ/mol]*	*ΔS [kJ/K·mol]*	K_{eq} *[-]*
-6.21	2.377	27.88	12.8

Conclusion

In the present study, the elimination of *BB* dye from water has been done, and the best adsorption efficiency of dye is 120.56 mg /g, at a weight of *RC* 0.08 g/100 mL, the percentage of dye increases with the amount *of RC* increase is due to a rise in the surface area resulting in the number of particles with increased active surface sites number for the adsorption and saturation as a result of no availability of dye molecules to adsorption. The adsorption method followed the model Freundlich isotherm with a maximum adsorption capability of 120 mg/g. The value of Gibbs free energy was negative which means the process is spontaneous. While enthalpy changes are positive (endothermic). The values of the positive of ΔS are not very large and agree with the decrease in the degree of freedom. The performance and reuse of *RC* by using 0.01 N HCl in the adsorption process of dyes were investigated up to 6 cycle under the best conditions, and moreover, desorption studies portend that the *RC* can be used frequently for the Re-generation of dye. Further research is suggested to investigate the possibility of using *Ricinus communis*, RC, to remove many contaminants such as heavy elements and pesticides and herbicides, and preparing new surfaces that are inexpensive, and environmentally friendly.

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